Grain yield stability analysis of Boro rice (*Oryza sativa* L.) using AMMI and GGE biplot models under varying sowing dates and NPK doses in the Upper Brahmaputra region of Assam

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Abstract: A field experiment was conducted during the 2020–21 *Boro* (spring rice) season to evaluate grain yield stability in 12 rice (*Oryza sativa* L.) genotypes under varying NPK doses and sowing dates, using randomized block design (RBD). The study aimed to analyze genotype × environment (G × E) interactions through AMMI (Additive Main Effects and Multiplicative Interaction) and GGE (Genotype and Genotype × Environment) biplot models. AMMI analysis explained 61.1% of the total G × E variance, with the first interaction principal component (IPC1) and second interaction principal component (IPC2) accounting for 33.6% and 27.5% of the variation, respectively. G3 contributed the most to the interaction, followed by G9, G2, G5, and G4. The AMMI 1 biplot revealed G7 as the most stable and high-yielding genotype, followed by G1, G11, G10, and G12.

The GGE biplot analysis explained 72.67% of the total variance through two principal components, PC1 (52.88%) and PC2 (19.79%). Among the environments, E6, E7, and E5 were identified as the most stable, while E2, E4, E8, E1, and E3 were more variable. Based on both AMMI and GGE analyses, genotypes G7, G1, G11, G10, and G12 were identified as the most stable and high-yielding. Genotype G7 showed specific adaptation to high NPK doses in the second sowing date (E7 and E8) and is recommended for late sowing under high-input management. Genotype G1 demonstrated suitability for low NPK doses across both early and late sowing dates (E1, E2, E5, and E6). This study provides insights into genotype performance and stability, aiding in targeted recommendations for sustainable rice production.

Keywords: Boro rice, AMMI analysis, GGE biplot, genotype × environment interaction, grain yield stability, NPK dose, sowing dates, rice genotypes.

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1. Introduction

Rice (*Oryza sativa* L.) is a staple food for a large portion of the global population and holds immense significance, particularly in Asia, including India. The leading rice-producing countries worldwide include China, India, Indonesia, Bangladesh, Vietnam, Thailand, and Myanmar, with India consistently ranking among the top producers alongside China. In India, rice cultivation spans across diverse agro-climatic regions, with major producing states being West Bengal, Punjab, Uttar Pradesh, Andhra Pradesh, and Tamil Nadu. In Assam, rice is cultivated during three distinct seasons: *Sali* (kharif), *Ahu* (pre-kharif), and *Boro* (rabi).

Boro rice, or winter rice, is grown from November to May and is recognized for its high yield potential. This crop thrives in cooler temperatures and is primarily irrigated, as the winter season in Assam is relatively dry. Farmers utilize water from rivers, canals, and tube wells to meet the irrigation requirements. While a recommended package of practices exists for *Boro* rice cultivation in Assam, variations in farmers' economic conditions necessitate alternative strategies to optimize inputs such as nitrogen, phosphorus, and potassium (NPK).

The present study aims to evaluate *Boro* rice genotypes under different NPK doses and sowing dates to identify varieties suitable for both low- and high-input systems. Additionally, the study investigates genotype × environment (G × E) interactions using the AMMI (Additive Main Effects and Multiplicative Interaction) model (Gauch 2008) and the GGE (Genotype and Genotype × Environment) biplot approach (Yan 2006).

The AMMI model effectively analyzes G × E interactions by combining the main effects of genotypes and environments with principal component analysis (Sharifi et al. 2017). The GGE biplot is a robust graphical method that identifies genotypes with superior yield and stability across environments, as well as environments that are representative and discriminating (Donoso-Ñanculao *et al.* 2016). This dual approach provides critical insights into the adaptability and performance of genotypes across diverse conditions.

Hence, the present study was undertaken to evaluate the performance and stability of *Boro* rice genotypes under different NPK doses and sowing dates, aiming to recommend suitable varieties for specific or wide-scale cultivation across breeding zones in Assam.

2. Materials and Methods

2.1 Site Description

Field experiments were conducted during the *Boro* season of 2020–21 at the Instructional Cum Research (ICR) Farm, Assam Agricultural University, Jorhat, Assam (26.20° N, 92.94° E). The experimental site, situated at an elevation of 86.6 m, is characterized by alluvial soils of the Upper Brahmaputra Valley Zone (UBVZ) with a pH of 5.69, organic carbon content of 0.66%, available nitrogen (N) of 283.42 kg/ha, available phosphorus (P) of 29.64 kg/ha, and available potassium (K) of 167.81 kg/ha. Monthly weather data recorded during the experimental period are presented in Table 1.

Table 1. Monthly weather data during the experiment

Month/Year	Max T(°c)	Min T(°c)	Avg T(°c)	RF(mm)	BSSH(hr)
Nov-2020	26.40	12.73	26.70	0.00	7.08
Dec-2020	25.75	10.89	21.65	0.13	6.69
Jan-2021	23.48	10.39	17.19	0.46	4.35
Feb-2021	27.29	11.51	17.14	0.09	6.30
March-2021	29.35	16.18	19.84	1.69	4.57
April-2021	31.71	18.61	22.33	1.43	6.25
May-2021	30.95	21.87	25.80	5.52	3.07
June-2021	32.01	24.28	26.39	9.00	3.71
July-2021	33.12	25.20	28.26	5.50	4.44

2.2 Plant Materials and Growing Conditions

Twelve *Boro* rice (*Oryza sativa* L.) genotypes were sourced from the Regional Agricultural Research Station (RARS), Shillongani, Nagaon, and the Seed Technology Research (STR) unit, National Seed Project (Crops), AAU, Jorhat. Seeds were pre-germinated, and nurseries were raised with a one-month interval on 27 November 2020 and 27 December 2020. Transplanting was carried out at the 4–5 leaf stage on 28 January 2021 and 28 February 2021, respectively. Each plot measured 8 m^2/genotype/replication, with 1 m spacing between replications and 0.6 m spacing between plots within a replication. Plots were separated by bunds to prevent water and nutrient movement between treatments.

Four NPK doses (20:10:10, 40:20:20, 60:30:30, and 80:40:40 kg/ha) were evaluated under two sowing dates, creating eight distinct environments (E1 to E8). The recommended NPK dose of 60:30:30 kg/ha served as a benchmark. The experiment was laid out in a randomized block design (RBD) with three replications. Other agronomic practices were followed as per the *Rabi* crop recommendations of Assam Agricultural University (2015).

2.3 Statistical Analysis

Grain yield stability analysis was conducted using AMMI (Additive Main Effects and Multiplicative Interaction) and GGE (Genotype and Genotype × Environment) biplot models. Statistical computations were performed in R software.

The AMMI model, as described by Hongyu *et al.* (2014), integrates additive main effects of genotypes (gi) and environments (ej) with principal component analysis (PCA) to decompose genotype × environment (G × E) interactions. The AMMI equation is expressed as:

$$Y_{ijr}=\mu+g_i+e_j+\sum_{n=1}^{N}\lambda_n\alpha_{in}\gamma_{jn}+\rho_{ijr}$$

where YijrY_{ijr}Yijr is the performance of the *i*th genotype in the *j*th environment within the *r*th replication, μ\muμ is the grand mean, gig_igi and eje_jej are deviations of genotype and environment main effects from the grand mean, λn\lambda_nλn is the singular value for interaction principal component (IPC) axis *n*, αin\alpha_{in}αin and γjn\gamma_{jn}γjn are IPC scores for genotype and environment, respectively, and ρijr\rho_{ijr}ρijr represents residuals.

The GGE biplot model was used for multi-environment trial (MET) analysis as per Yan and Kang (2002). This approach evaluates genotypes based on both genotype and G × E interactions, employing singular value decomposition (SVD) of environment-centered data. The GGE biplot equation is expressed as:

$$Y_{ij}-\mu-\eta_j=G_{i1}E_{j1}+G_{i2}E_{j2}+\varepsilon_{ij}$$

where Gi1G_{i1}Gi1 and Gi2G_{i2}Gi2 are genotype scores for principal components PC1 and PC2, Ej1E_{j1}Ej1 and Ej2E_{j2}Ej2 are environmental scores for PC1 and PC2, and εij\varepsilon_{ij}εij is the residual error.

Key analyses included:

1. Polygon views of GGE biplots for "which-won-where" patterns to identify superior genotypes across environments.
2. Genotype rankings based on yield and stability.
3. Comparison of genotypes with an ideal standard.
4. Evaluation of environments for representativeness and discriminating ability.
5. Contrasts between specific genotypes (Akter *et al.*, 2015; Yan, 2006).

3. Results and Discussion

3.1 Yield Performance

The grain yield performance of the 12 *Boro* rice (*Oryza sativa* L.) genotypes across eight environments is presented in Table 2. The mean yield performance of each genotype (G1–G12) was evaluated in all environments (E1–E8). In E1, G3 (3864.37 kg/ha) recorded the highest yield, followed by G7, G9, G11, G12, and G10, whereas G2 (2359.89 kg/ha) had the lowest yield. In E2, G7 (4187.13 kg/ha) showed the highest yield, followed by G11, G12, G9, and G10, with G2 (2545.31

kg/ha) again being the lowest yielder. Similarly, in E3, G4 (5294.95 kg/ha) had the highest yield, followed by G11, G1, G3, and G7, while G2 (3439.93 kg/ha) recorded the lowest yield. In E4, G7 (4889.99 kg/ha) outperformed others, followed by G1, G11, and G8, while G2 (3766.94 kg/ha) yielded the lowest.

In E5, G3 (3065.47 kg/ha) recorded the highest yield, followed by G9, G4, G7, and G1, with G5 (2295.76 kg/ha) yielding the least. In E6, G9 (3662.22 kg/ha) was the top performer, followed by G10, G11, G6, and G12, while G4 (2510.03 kg/ha) recorded the lowest yield. In E7, G10 (4212.04 kg/ha) had the highest yield, followed by G12, G7, G1, and G11, while G8 (3417.43 kg/ha) was the lowest yielder. Lastly, in E8, G7 (4523.53 kg/ha) showed the highest yield, followed by G1, G5, and G8, while G4 (3336.31 kg/ha) had the lowest performance. These results indicate that specific genotypes are more suitable for specific environments based solely on grain yield performance, excluding genotype × environment (G × E) interactions.

Genotype	**1st date of sowing**				**2nd date of sowing**				
Code	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**Mean**
Biplab G1	3526.11	3741.03	4792.50	4884.43	2635.64	3239.51	3950.24	4175.72	3868.15
RanjitSub-1 G2	2359.89	2545.31	3439.93	3766.94	2417.16	2717.66	3791.79	3562.07	3075.09
Mashuri G3	3864.37	3674.92	4571.78	4080.48	3065.47	2964.31	3588.25	3362.99	3646.57
Swarnadh G4	3510.90	3621.62	5294.95	4805.32	2740.16	2510.03	3667.05	3332.31	3685.29
Jaymati G5	2874.40	3803.82	4509.43	4339.55	2295.76	3227.94	3907.19	4122.18	3635.03
CiherangSub-1G6	2958.63	3728.39	4167.02	3922.14	2497.59	3333.92	3570.08	3540.92	3464.84
IR-68 G7	3768.40	4187.13	4660.24	4889.99	2673.57	3419.64	4088.65	4522.53	4026.27
IR-50 G8	3555.38	3613.44	3918.44	4429.92	2387.15	2802.14	3417.43	4087.27	3526.40
JR-60 G9	3723.96	3935.54	4406.22	4095.66	2916.76	3662.22	3595.87	3367.21	3712.93
Jyotiprasad G10	3556.00	3899.37	4561.57	4284.52	2413.30	3553.33	4212.04	4017.08	3812.15
Dinanath G11	3681.11	4155.62	4876.80	4602.50	2571.64	3526.83	3947.50	3807.85	3896.23
Kanaklata G12	3585.47	3941.25	4549.21	4338.67	2440.51	3268.47	4092.33	3797.92	3751.73

Table 2. Yield (Kg/ha) performance of 12 boro rice varieties under different fertilizer doses and dates of sowing

3.2 AMMI Analysis of Variance

The AMMI analysis of variance (ANOVA) for grain yield (Table 3) revealed that the sum of squares for genotype and environment were highly significant, indicating substantial variability among genotypes and environments. The significant G × E interaction underscores the differential response of genotypes across environments.

Table: 3. AMMI analysis of variance for yield performance of 12 genotypes across eight environments

Sources of variation	**DF**	**Sum sq**	**Mean sq**	**F value**	**Pr(>F)**
Environment	7	99736902.80	14248128.98	1333.68	7.23e-149**
Replication	16	184529.10	11533.07	1.08	3.78e-01
Genotype	11	15969675.00	1451788.64	135.90	7.30e-80**
Environment x Genotype	77	23251816.90	301971.65	28.27	6.15e-69**
Residual	176	1880267.80	10683.34		

3.3 AMMI Biplot Analysis

The first principal component (PC1) explained 33.6% of the total variation due to G × E interaction, while the second principal component (PC2) explained 27.5%, cumulatively accounting for 61.1% of the variation. The AMMI biplot (Fig. 1) illustrates the relationship between mean yield performance and PC1 scores. High-yielding genotypes with low PC1 scores (closer to zero) are desirable due to their stability across environments.

Genotype G7 (4026.27 kg/ha) was the highest yielder overall, followed by G11 (3896.23 kg/ha), G1 (3868.15 kg/ha), G10 (3812.15 kg/ha), G12 (3751.73 kg/ha), and G9 (3712.93 kg/ha). Conversely, G2 (3075.09 kg/ha) was the lowest yielder, followed by G6 (3464.84 kg/ha) and G8 (3526.40 kg/ha). Considering both yield and stability, G1 was identified as the most stable genotype, with G5, G12, and G9 also showing stability due to their lower PC1 scores (near zero).

Genotypes located near a particular environment in the biplot are considered better suited for that environment. For example, G2, G6, and G8 were more suited for E6, while G3, G4, and G5 were suitable for E2. Genotypes contributing more to G × E interaction were positioned farther from the origin in the biplot, indicating higher interaction variability.

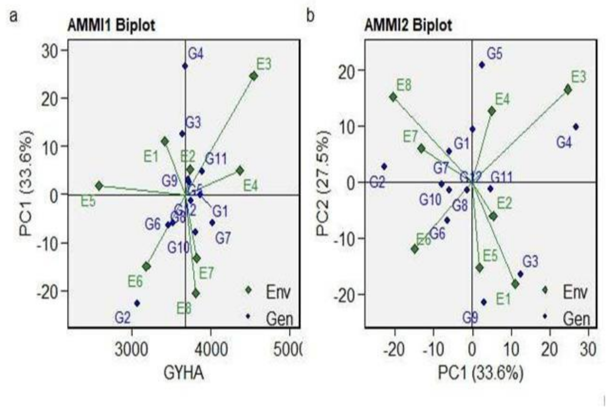

Figure 1 & 2: AMMI biplots of different rice genotypes and environments

3.4 GGE Biplot Analysis

The GGE biplot analysis explained 72.67% of the total G × E interaction, with PC1 and PC2 accounting for 52.88% and 19.79%, respectively. The concentric circles in the GGE biplot (Fig. 3) assess the discriminative power of environments, with E2 being the most suitable environment due to its proximity to the center. E5 was identified as the most stable environment, while E2, E4, and E8 showed higher instability.

The biplot ranked genotypes based on yield and stability, with G7 positioned closest to the center, indicating its superiority in yield and stability. Other desirable genotypes included G11, G1, G10, G5, and G12. Genotypes such as G2, G6, G8, G3, G9, and G4 were located farther from the ideal genotype, indicating lower yield performance and stability. (Fig 4)

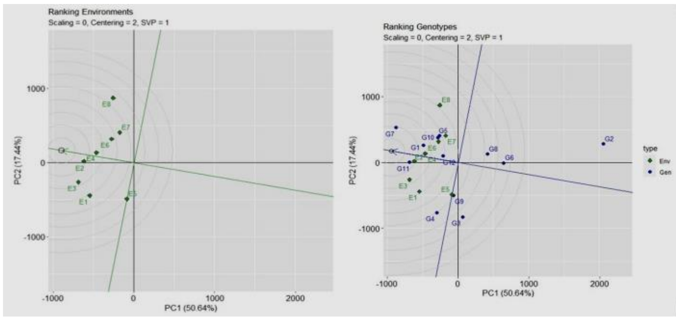

Figure 3 & 4: GGE biplots of different rice genotypes and environments

The "which-won-where" biplot (Fig. 5) identified two mega-environments. E8, E7, E6, E2, and E4 formed one mega-environment, with G7 and G11 being the best performers. E1, E3, and E5 constituted another mega-environment, where G4 and G3 excelled. The genotypes at the vertices of the polygon performed best in specific environments, whereas genotypes closer to the origin displayed stability across environments.

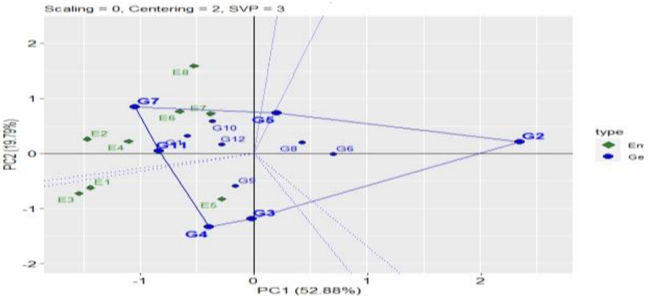
Figure 5: Which won where of the GGE biplot

3.5 Stability and Adaptability

Genotypes G7, G11, G1, G10, and G12 were high-yielding and relatively stable, making them suitable for diverse environments. G7, being nearest to the center, emerged as the ideal genotype for yield and stability. Genotypes G3, G9, and G4 contributed more to G × E interaction, showing specificity for certain environments but lesser adaptability. Environments E6 and E7 were identified as stable, while E2, E4, and E8 were less stable.

These findings highlight the importance of selecting genotypes like G7 for broader adaptability and stable performance. The AMMI and GGE biplot methodologies together provide robust insights into genotype stability and environment-specific adaptability, aligning with similar studies (Islam *et al.*, 2015).

4. Conclusion

The study revealed that genotype × environment (G × E) interaction, along with the inherent genetic makeup of the genotypes and environmental factors, significantly influenced the grain yield performance of rice (*Oryza sativa* L.). Grain yield, being a complex trait, is shaped by the interplay of multiple traits and environmental variables, both directly and indirectly. The application of AMMI and GGE statistical models in this study facilitated the identification of high-yielding and stable genotypes across diverse environments.

The AMMI model indicated that genotypes and environments contributed substantially to the total variability in grain yield, while the GGE biplot analysis effectively visualized the "which-won-where" patterns and identified genotypes with superior yield performance and stability. Among the tested genotypes, G7, G1, G11, G10, and G12 emerged as the most stable and high-yielding. These genotypes are recommended for cultivation at AAU, Jorhat, and similar agro-ecological zones.

Specifically, G7 demonstrated high adaptability to high NPK doses and later sowing dates (E7 and E8), making it suitable for production under these conditions. Conversely, G1 showed consistent performance under low NPK doses across both sowing dates (E1, E2, E5, and E6) and could be recommended for cultivation in breeding zones with comparable conditions. The findings provide valuable insights for enhancing rice productivity through targeted genotype selection and precise environmental management strategies.

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